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PATENT SPECIFICATION

734,871

Date of Application and filing Complete Specification: Feb. 2, 1953
No. 2956/53.
Application made in United States of America on June 14, 1952.
Complete Specification Published: Aug. 10, 1955.

Index at acceptance:—Class 39(1), D(10F: 18A: 40F).

COMPLETE SPECIFICATION

Improvements in or relating to Magnetrons

We, RAYTHEON MANUFACTURING COMPANY, a corporation organised under the laws of the State of Delaware, United States of America, of 55, Chapel Street, Newton, County of Middlesex, Commonwealth of Massachusetts, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention concerns a high-frequency electrical oscillator of the multi-resonator magnetron type and, more specifically, a strapped magnetron, and is particularly directed to improvements in strapped magnetrons for producing the proper loading of both doublets of the mode adjacent to the desired or pi mode.

Multi-resonator magnetrons, including strapped multi-resonator magnetrons should have an anode-resonant system such that the tube is capable of stable operation in the principle or pi mode of resonance, that is, the mode in which adjacent resonators are π radians out of phase. Stable operation in the desired mode is complicated owing to the existence of a plurality of resonances or modes associated with the multi-resonator anode structure of a magnetron, several of which may be excited by approximately the same electronic operating condition, such as anode voltage, electron current or magnetic field. In most magnetrons, however, the pi mode and the mode adjacent in order number to the pi mode are the only ones that are of practical concern.

In certain cases, it is impractical to adjust the frequency relation of these modes in such a manner that different electronic conditions are necessary for their excitation, in which case, it is necessary to change the characteristics of the mode adjacent the pi mode so that the pi mode will predominate.

The pi mode and the mode adjacent thereto differ in order number; that is the adjacent mode has either one more or one less phase variation in its azimuthal-field pattern than the pi mode. Furthermore, the adjacent mode is a doublet; that is, it consists of two resonances whose field patterns, in a cylindrical multi-cavity anode type magnetron for example, contain the same number of angular variations around the cylindrical anode structure; in any case the respective field patterns differ from each other by ninety electrical degrees in the angular position of their pattern maxima and minima. Because of the asymmetry introduced into the anode-resonant system, by the usual ouput-coupling device attached to a single cavity of the anode system, the doublets of the adjacent mode are so oriented that one is coupled to the output system while the other is not. Referring again to a cylindrical magnetron, the degree of coupling of each doublet of a given mode is thus seen to be dependent upon the orientation with respect to the anode structure of both doublets of the mode.

doublet = two resonances angularly displaced

Since the ratio of build-up of rf energy in the magnetron cavity is directly proportional to the Q of the resonance, it is desirable, in order that the pi mode be the dominant mode, that the Q's of the undesired resonance be less than that of the pi mode. With anodes containing no asymmetry other than that owing to the output-coupling means, this condition does not exist, since one doublet of the adjacent mode remains uncoupled to the output system.

Prior attempts made to orient these doublets in strapped multi-resonator magnetrons so as to change their loading have usually been of the form of strap breaks or adjustment of the end cavity geometry.

Strap breaks have been introduced in

π mode = adjacent resonators π radians out of phase

high-current regions in order to disrupt the existing adjacent mode pattern by a maximum amount. This has the undesirable feature of causing a substantial change in the frequency in one of the doublets or of causing the appearance of a new mode considerably removed in frequency from the original adjacent mode, and sometimes markedly affecting the characteristics of the pi mode itself.

The adjustment of end cavity geometry is quite frequency sensitive and, therefore, ineffective for tubes whose frequency is not fixed, i.e., tunable magnetrons.

In accordance with the invention there is provided a magnetron comprising a cathode, an anode structure containing a plurality of segments defining cavity resonators, a plurality of electrically-conductive members each interconnecting alternate segments, and an output coupling associated with one of said resonators, said magnetron being capable of operation in a desired mode which is advantageously coupled to said output coupling and in a doublet mode adjacent said desired mode, said doublet mode consisting of oscillations having field patterns differing from each other by ninety electrical degrees in the relative positions of their pattern maxima and minima, characterised by structural asymmetries in the form of deliberately-introduced distortions in the electrically-conductive members, said distortions being positioned with respect to the output coupling so that they adjust the position of each doublet wave form of said doublet mode so that each doublet is coupled to said output coupling substantially equally to the other to an extent sufficient to prevent the build-up of oscillations of either doublet in the output coupling.

The degree of coupling between the doublets of the adjacent mode and the output at a single cavity of a multi-cavity magnetron is controlled by introducing an asymmetry or asymmetries, in addition to the asymmetry owing to the output-coupling means, into the anode structure at points located on one or both critical load axes of the respective doublets of an adjacent mode, said axes being represented in a cylindrical anode magnetron by lines passing through the geometrical center of said magnetron and angularly displaced by a critical load angle from an output axis passing through the center of said output-coupling means and the geometrical center of said magnetron. Having regard to the disposition of the critical load axes for a given magnetron, the asymmetries introduced thereon provide for equal coupling of both doublets of the mode or modes adjacent the pi mode to the output-coupling means. This asymmetry is generally quite small and may be produced by a small discontinuity, such as a bent strap, to change the natural resonant frequency of the associated cavity by an amount of the order of one or two per cent.

The optimum coupling is determined by said critical load angle, which, for an otherwise symmetrical anode except for the output coupling means, will generally be forty-five degrees. The angle between the two critical load axes is always equal to ninety degrees.

In a perfectly symmetrical anode (except for the output-coupling means, it is necessary to introduce an asymmetry (e.g. bend the straps) only at any single forty-five degree multiple position on one of said critical load axes; however, because of small practical construction asymmetries, it is desirable to introduce asymmetries (e.g., bend the straps) at at least four points to insure that no random asymmetries mask the effect of those purposely introduced. Furthermore, the type of asymmetry introduced at two of the diametrically opposite points on one crtical load axis should be of the reverse type from those introduced at the two diametrically opposite points on the other critical load axis. In other words, if an asymmetry of a kind that will tend to raise the frequency (reduction of strap inductance or capacitance) is placed at $+45°$ and $+225°$ with respect to the output-coupling means, an asymmetry tending to lower the frequency should be placed at the $-45°$ and $-225°$ positions. Otherwise, the effects of the asymmetries will neutralize one another and the output discontinuity will predominate and fix the orientation of the doublets as it does in a symmetrical anode.

If however, the anode block contains sufficiently large asymmetries other than the output-coupling asymmetry, such as imperfections in the anode block resulting from the manufacturing process, said critical load axes may depart somewhat from forty-five degrees with respect to the output axis. The type of external magnetron load also has a slight effect upon the critical load angle at which optimum couping of the two doublets is attained.

Furthermore, when asymmetries are introduced into a multi-cavity magnetron structure according to this invention, satisfactory operation in the pi mode has been found to exist in practice

in certain types of magnetrons even though the loading of the two doublets of the adjacent mode is not exactly equal. For instance, it has been found that a departure of as much as fifteen degrees from the theoretical critical load angle of forty-five degrees may be made in some magnetrons while still obtaining sufficient coupling of the adjacent mode doublets to the output-coupling means to prevent operation in the undesired adjacent mode.

By means of this invention, the desired loading of the doublets may be obtained without causing excessive and undesirable changes in the adjacent mode frequencies and in separation of the adjacent mode from the pi mode, as is the case with magnetrons employing strap breaks or other drastic asymmetries. Secondly, this invention permits a loading of the doublets of the adjacent mode which is comparatively insensitive to frequency as compared with the frequency-sensitive adjustment of end cavity geometry for accomplishing doublet loading in fixed frequency tubes. Thus, this invention provides for practical and convenient loading of the adjacent mode doublet in a tunable magnetron.

In the drawings:

Fig. 1 is a transverse view, partly in section, of a multiple resonator magnetron of the strapped-anode type which has been modified as shown in Fig. 2 according to the invention;

Fig. 2 is a development of the anode vanes showing how to practice the present invention by making changes in certain strapping details; and

Fig. 3 shows the distribution of anode rf potenial for the pi mode and doublets of the lower adjacent mode of a strapped resonator system having the same number of cavities as that which is shown in Fig. 1.

Fig. 1 shows a magnetron generally indicated by reference numeral 10 and comprising a cathode 11 and anode block 12 including a plurality of anode vanes 14a, 14b, 14c, and so forth, attached to a shoulder portion 13 of anode block 12.

A pair of concentrically-arranged closed annular straps 15 and 16 is shielded from the magnetron interaction space by being positioned in slots 17 and 17[1], arranged between the upper faces of anode vanes 14. These straps are preferably in the form of flexible ribbons or wires of an electrically-conductive material, such as copper or silver. Inner strap 15 is attached to the inner edges of slots 17, as by brazing, while outer strap 16 is similarly attached to the outer edges of slot 17[1], as shown in Fig. 1. The alternate slots 17 and 17[1] are offset or staggered with respect to one another so that strap 15 is attached to alternate anode vanes 14a, 14c, 14e, and so forth, while strap 16 is attached to anode vanes 14b, 14d, 14f, and so forth, intermediate to those to which strap 15 is attached.

As shown in Fig. 2, the straps are preferably secured to the top portion of the corresponding slots for reasons which will be apparent later.

Although the strapping shown in Fig. 1 is of the shielded double-ring type, the invention is not limited thereto and single-ring strapping, either shielded or unshielded, or echelon strapping may also be used. Furthermore, an annular strap may be located in slots in opposite faces of anode vanes 14, as shown in British Specification No. 654,648. To reduce undesirable capacitance effects between surfaces of the straps and the cathode, a shielded strap, such as shown in Fig. 1, is preferred to an unshielded strap.

The invention, furthermore, is not limited to magnetrons having resonators of the vane type. For example, any of the aforesaid types of strapping may be incorporated in a magnetron having either a slot-type cavity resonator, or a hole-and-slot type resonant structure, such as shown and described in the aforesaid British patent Specification. In the case of the hole-and-slot type magnetron, the resonators may be connected together by a pair of closed wire rings secured within annular grooves formed in one of the end faces of the anode block.

Referring again to Fig. 1, the oscillations produced in the magnetron may be led out from the tube by means of an inductive coupling loop 25 (not shown in Fig. 1) which may be inserted into one of the resonant cavities 18 through a radial bore 19 in anode block 12. The coupling means is conventional and is omitted from Fig. 1 of the drawing in order to simplify the description of the operation of the invention. A wave-guide coupling means may be employed in lieu of the coupling loop.

The output axis 20 passing through the center of output bore 19 and the geometrical centre of the magnetron serves as axis of reference in so far as the rotational position of the anode-field pattern is concerned. In magnetrons which are symmetrical except for the output-coupling means positioned in or near one of the cavities, the coupling means serves to fix the rotational position of the field pattern.

The distribution of anode rf potential

for the pi mode and the adjacent doublet mode in the resonator system of Fig. 1 is shown in Fig. 3. The anode is shown developed from the cylindrical form with the various anode vanes appearing as rectangles. The output-coupling loop is represented by reference numeral 25. The full lines represent the potential variation with angular displacement θ from the asymmetry introduced by the output-coupling means on axis 20 for the first doublet of the mode adjacent the pi mode. The dashed lines represent the potential variation associated with the second doublet of said adjacent mode with angle θ measured from output axis 20.

The anode potential for the two doublets of the mode adjacent the pi mode, or the $\frac{N}{2}\pm1$ mode, where N is the number of cavities, is shown by the wave patterns in Fig. 3a. For an anode having 16 cavities, as in the anode structure of Fig. 1, said doublets are those of either the n=7 or n=9 mode where n is the order number of the mode. For the anode of Fig. 1 the pi mode is the n=8 mode. The doublets of the n=7 mode are shown in Fig. 3.

It should be understood, however, that the invention is not restricted to a cylindrical anode structure, or in the case of a cylindrical anode to anode structure having 16 cavities; any even number of anode cavities may be used in a cylindrical anode. From the wave forms of Fig. 3a, it is evident that the instantaneous voltage on anode segment or vane 14q for the first doublet is almost at the maximum value, as shown by point A. Similarly, the instantaneous voltage for the first doublet at adjacent anode vane 14a is at approximately the same value as that at vane 14q but of reversed polarity, as shown at point B. There is, therefore, a considerable difference of potential between the anode segments bounding output cavity 18; the rf current flow along the output cavity vanes 14a and 14q and, hence, the magnetic flux in the output cavity is relatively large. The first doublet is thus strongly coupled to the output load of the magnetron. On the other hand, the instantaneous rf voltages appearing at output vanes 14q and 14a for the second doublet are equal in magnitude and phase, as shown at points C and D, respectively, so that there is no coupling of this second doublet to the output.

Since the oscillation in a loosely-coupled mode has a high Q because of its being dampened only by losses in the resonator structure itself, said oscillation will build up more rapidly under electron drive than that of the desired pi mode, and this undesirable oscillation, either steady or intermittent, in the loosely-coupled doublet of the adjacent mode occurs.

In order to eliminate the aforesaid difficulty inherent in unequal loading of the adjacent mode doublets, an arrangement as shown in Figure 2 may be used to introduce desired asymmetries according to the invention in a strapped multi-cavity cylindrical anode magnetron. A development of the cylindrical anode block is shown in Figure 2 with the straps and anode vanes bearing corresponding reference numerals to those of Figure 1.

It should be understood that although Figure 1 illustrates single closed annular straps 15 and 16, it is possible that a plurality of separate straps may be soldered to alternate anode segments. For purposes of discussion and for establishing terminology used in the claims, that portion of annular straps 15 and 16, which interconnects two alternate vanes or segments of the anode-resonant structure, will be referred to as a separate strap. In other words, straps 15 and 16 will each be considered as eight separate straps all of which interconnect a pair of alternate vanes.

Referring back to Figure 1, the critical load axes 30 and 31 are each displaced from output axis 20 by an angle of forty-five degrees. The straps which cross critical load axis 30 are pulled up, as shown in Fig. 2, thereby tending to increase the natural resonant frequency of the cavities formed by the vanes to which these straps are attached. For instance, the inner strap 15 interconnecting vanes 14a and 14c and the outer strap 16 interconnecting vanes 14b and 14d are lifted up above the normal position, which, as here shown, is coincident with the top face of the anode vanes. Diametrically opposite the aforesaid straps, another pair of straps crossing axis 30 is also pulled up; this pair includes the inner strap interconnecting anode vanes 14i and 14k and the outer strap connecting together vanes 14j and 14l.

The straps which cross critical load axis 31 are pushed down, thereby tending to decrease the natural resonant frequency of the cavities formed by the vanes to which these straps are attached. In Figs. 1 and 2, these straps are the inner straps interconnecting vanes 14e and 14g and vanes 14m and 14p and the outer straps interconnecting vanes 14f and 14h and vanes 14n and 14q. The remaining straps are undistorted and, as

Raise freq = reduce capacitance

previously stated, lie in a plane parallel with the plane of the top faces of the anode vanes.

The straps which cross critical load axis 30 may be pushed down rather than pulled up, in which case the straps crossing axis 31 would be pulled up. In other words, if an asymmetry of the type tending to increase the cavity-resonator frequency, such as a reduction of strap inductance or capacitance, is introduced at positions displaced from the output-coupling means by angles of +45° and +225°, it follows that an asymmetry of a type tending to decrease the frequency should be placed at points displaced from the output-coupling means by angles of −45° and −225°, that is, at angles of 45° displaced from the output axis 20. In this way, the effects of the asymmetries will not neutralize one another and the output discontinuity will not predominate and fix the orientation of the doublet, as it does in a symmetrical anode-resonant structure.

If the anode-resonant structure were symmetrical except for the output-coupling means, it would be necessary to bend the straps at only a single position displaced at forty-five degrees from the output axis; it is also possible to bend the straps at two diametrically opposite points located either on critical load axis 30 or on critical load axis 31. Because of practical construction asymmetries, however, it is preferable to bend the straps at the four points just described so as to eliminate any random asymmetries that may offset the effect of the asymmetry purposely introduced.

As previously stated, in some magnetrons containing more than the usual number of asymmetries as a result of imperfections in the manufacturing process, or in magnetrons operating into a large reactive load, the strapping asymmetry or asymmetries introduced into the anode block may be positioned at a critical load angle from the output axis different from forty-five degrees. Moreover, it has been found in practicing the present invention that the desired suppression of oscillation in the adjacent doublet mode may be accomplished even though the coupling of each doublet to the output-coupling means (load) is not exactly equal; the angle between the output axis 20 and the strap symmetry has been found to range from about 30 degrees to 60 degrees, depending on the factors above-mentioned and on the particular magnetron under consideration. Regardless of the value of the angle between the output axis 20 and the strap asymmetry, axes 30 and 31 will remain at right angles to one another.

For optimum coupling, the asymmetry or asymmetries should be so introduced that the points of maxima and minima for each doublet is located physically at angles of 45 degrees with output axis 20.

A shift of 45 electrical degrees corresponds to a shift in the voltage maxima and minima points of 45 physical degrees, as clearly shown in Fig. 3 for the $n=7$ case.

In Fig. 3b, both doublet wave patterns are displaced forty-five electrical degrees from the position shown in Fig. 3a. The instantaneous anode rf potential at output vanes 14q and 14a for the two doublets is now as shown at points E and F. The rf potential at anode vanes 14n and 14p which are displaced 45 physical degrees from anode output vanes 14q and 14a for the first and second doublets is as shown at points A', B', and C', D', respectively, of Fig. 3b, which correspond exactly to the potential existing at points A, B, C and D, respectively, at output vanes 14q and 14a of Fig. 3a. In other words, the physical displacement of the rf potential maxima and minima in degrees is equal to the electrical displacement in electrical degrees.

Inspection of Fig. 3b indicates that the potential difference between output anode vanes 14a and 14q for the first doublet has been reduced from that shown in Fig. 3a while that for the second doublet has increased. More important, however, is the fact that the aforesaid potential difference is now substantially equal for both doublets. This, of course, means that the two doublets are now coupled equally to the output-coupling means. It will be appreciated that this is the desired result for either the $n=7$ or the $n=9$ adjacent mode.

In Fig. 3c, the distribution of anode potential for the π or $n=8$ mode is shown. The pattern 27 has zero potential at each anode vane, as shown at points I and J, so that this pattern is meaningless. The pattern 28 displaced from pattern 27 by $\frac{\pi}{2}$ radians has a maximum value of potential at each anode vane, as shown at points K and L. It is evident, therefore, that the pi mode is not degenerate. The reorientation of the adjacent doublet mode, therefore, has no effect upon the operation of the magnetron in the pi mode.

As previously stated, the desired orientation of the two doublets of the adjacent mode may be produced by the introduction of asymmetry in the

strapped anode structure by shaping of the straps, other than by simple bends, to provide a parameter that will change the natural resonant frequency of a single cavity by an amount of the order of a few per cent. The illustration of one structural embodiment showing how to practice the invention in a strapped multi-resonator anode is not intended to limit the invention to that case.

What we claim is:—

1. A magnetron comprising a cathode, an anode structure containing a plurality of segments defining cavity resonators, a plurality of electrically-conductive members each interconnecting alternate segments, and an output coupling associated with one of said resonators, said magnetron being capable of operation in a desired mode which is advantageously coupled to said output coupling and in a doublet mode adjacent said desired mode, said doublet mode consisting of oscillations having field patterns differing from each other by ninety electrical degrees in the relative positions of their pattern maxima and minima, characterised by structural asymmetries in the form of deliberately-introduced distortions in the electrically-conductive members, said distortions being positioned with respect to the output coupling so that they adjust the position of each doublet wave form of said doublet mode so that each doublet is coupled to said output coupling substantially equally to the other to an extent sufficient to prevent the build-up of oscillations of either doublet in the output coupling.

2. A magnetron according to claim 1, having a cylindrical anode surrounding the cathode, said anode having an even number of resonators, characterised by bends in said electrically-conductive members to alter by only a few percent the resonance frequency of one or more not exceeding one-half of said resonators which are ninety, or a multiple of ninety degrees removed from each other about the axis of said anode.

3. A magnetron according to claim 2, characterised by four resonators having said bent electrically-conductive members, such resonators being uniformly distributed among the remaining resonators and having their resonance frequencies alternately above and below that of the remaining resonators.

4. A magnetron according to any of the preceding claims in which the anode resonators are defined by vanes and each electrically-conductive member is connected to the free ends of alternate vanes and skips over intervening vanes, characterised by said asymmetries being constituted by beds in said electrically-conductive members toward or away from selected intervening vanes whereby to raise or lower the resonance frequencies of the resonators adjoining such intervening vanes by the desired amount.

5. A magnetron according to any one of claims 2, 3 or 4 characterised by one or two of said asymmetries being located at positions approximately forty-five degrees from the output coupling measured about the cylindrical anode.

6. A magnetron according to any one of claims 2, 3 or 4 characterised by two asymmetries located at regions lying at opposite sides of the cathode along a diameter across said anode which diameter makes an angle approximately forty-five degrees with a line drawn through said output coupling and the cathode.

7. A magnetron according to Claim 6, characterized by two additional asymmetries located at regions lying at opposite sides of a second diameter across said anode which second diameter makes an angle of ninety degrees with the first-named diameter, the first-named two asymmetries being constructed to alter the resonance frequencies of their associated resonators in one direction and the second-named two asymmetries being constructed to alter the resonance frequencies of their associated cavities in the opposite direction.

8. A magnetron according to any one of Claims 2, 3 or 4 having eight or more resonators characterized by four asymmetries spaced equally about said anode structure, each associated with a particular resonator, the electrically-conductive members at said asymmetries being bent alternately toward and away from their associated resonators to raise or lower the resonance frequencies of their respective associated resonators with reference to the resonance frequency of remaining resonators.

9. A magnetron constructed, arranged and adapted to operate substantially as herein described with reference to, and as illustrated, in Figures 1 to 3 of the accompanying drawings.

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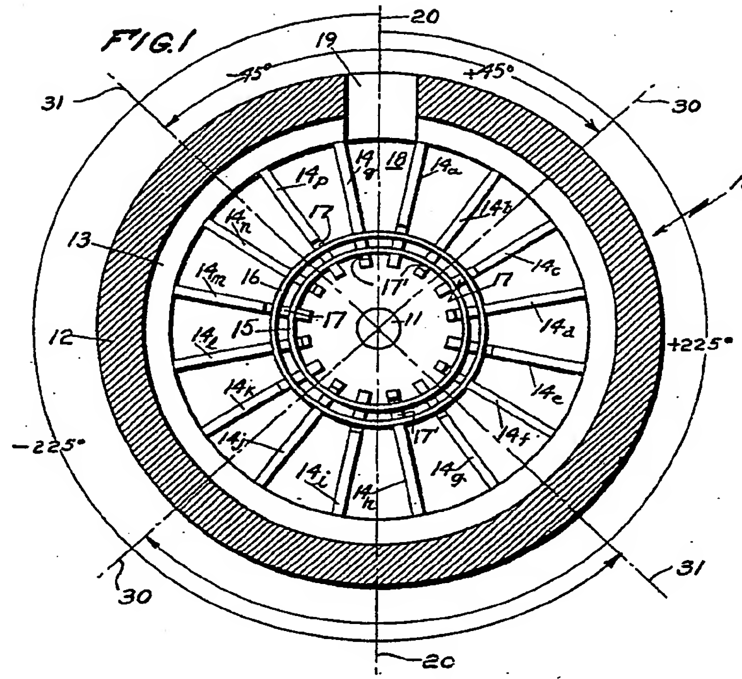
Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press.—1955. Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

FIG. 1



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+45°
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14c
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17'
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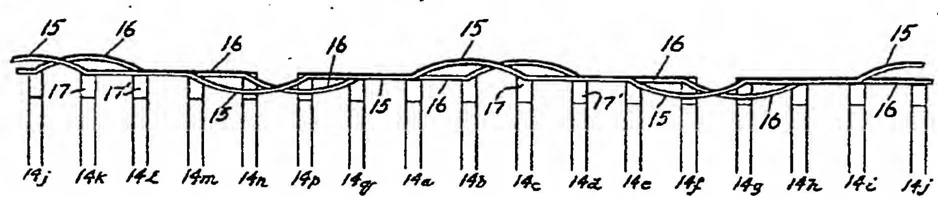
FIG. 2



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734,871 COMPLETE SPECIFICATION
2 SHEETS

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SHEETS 1 & 2

FIG.3

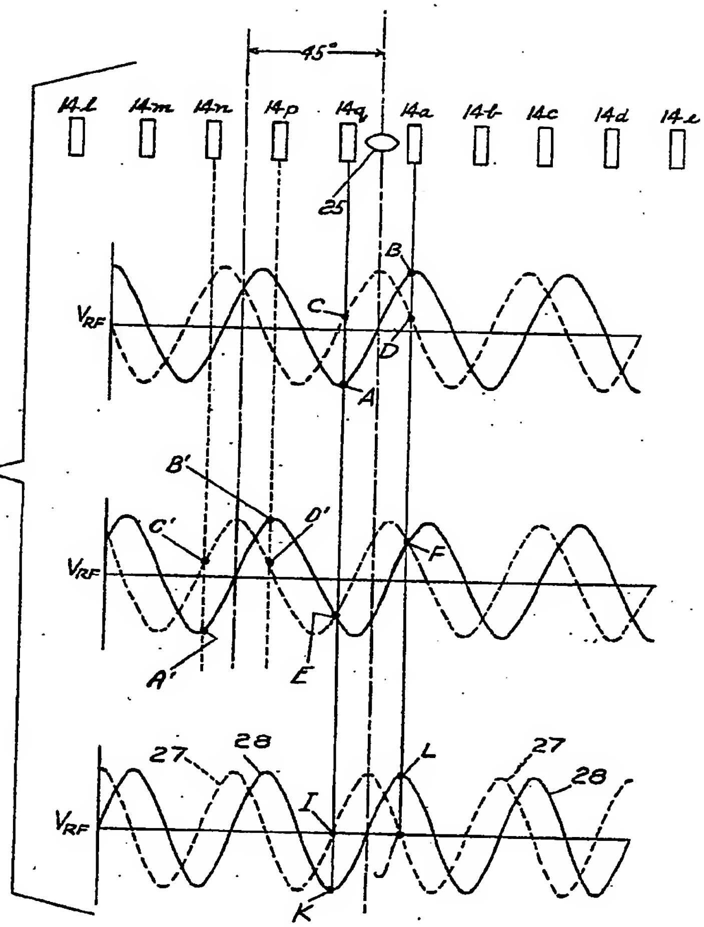

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FIG.1

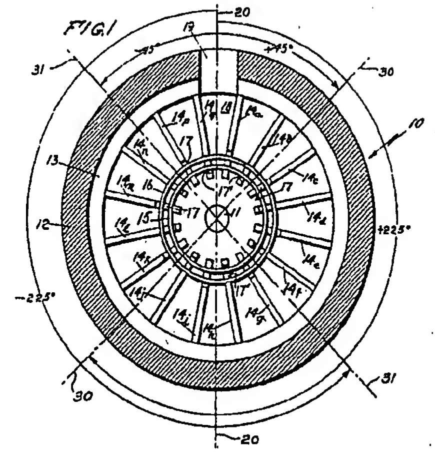

FIG.2

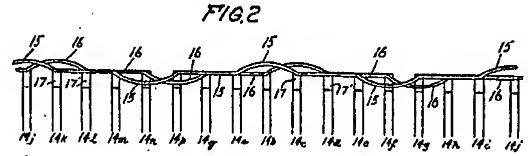

FIG.3